# Discussion on LEM design for phase II of ProtoDUNE-DP

# What are the ways of improvements ?
# 1/ the LEM itself (design/manufacturing)

- LEM paremeters : increase thickness, decrease number of holes ? Other parameters to optimize ? RIM ? Different size on the 2 sides ?

- Global quality of holes' drilling & RIM etching locally affecting electric field
  - With a 40 μm RIM, can an even more smooth RIM edge help ?
  - Improve RIM etching (etching defects for holes on borders and corners)
  - Other improvement in the manufacturing procedure ?
  - Covering of the RIM copper edges with an insulating layer
  - How to set-up the burn-in procedure to remove residual copper asperities ?

- Electric field increase on LEM borders & in the holes close to the borders/corners
  - Larger holes on the first few rows of holes from the border ?
  - LEM active area segmentation ?
  - Optimize the FR4 & copper guard rings dimensions on borders/corners
  - Covering of the copper edges with an insulator layer

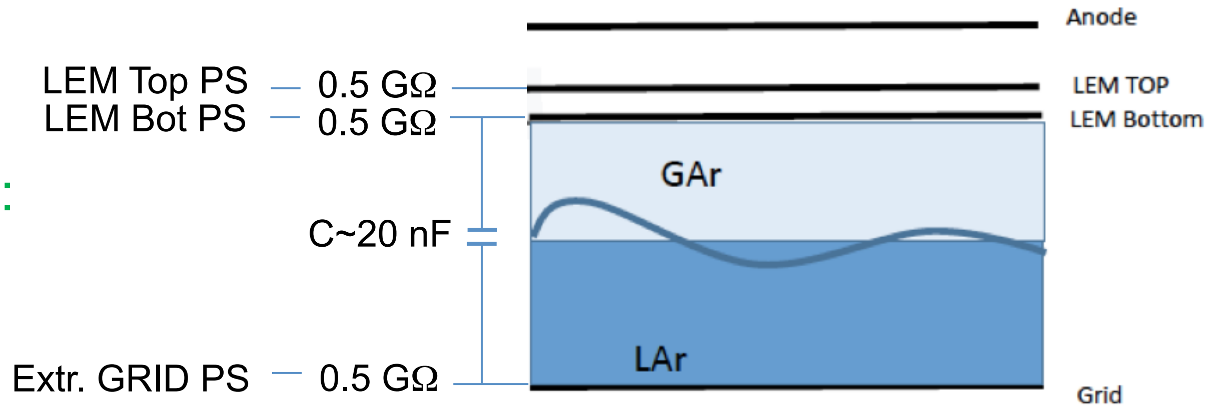
- Other ideas ? Resistive LEM, resistive anode, multi-LEMs, LEM with internal shaping eletrodes…

→ The R&D requires testing long term operation stability & ageing, both with individual LEMs in laboratory (3,3 bar argon) and with large area (> 4 LEMs) in DLAr conditions (« cold box »)

# What are the ways of improvements ?
# 2/ the LEM operation conditions

- Disentangle LEMs stability from instabilities (LEM ΔV) related to the capacitive coupling (depending on liquid surface stability) between the LEM bottom side and the extraction grid :

→ improve the High-Voltage electrical configuration of the CRP : lower the 0,5 GΩ quenching resistors & introduce a drain C between LEM & Grid.



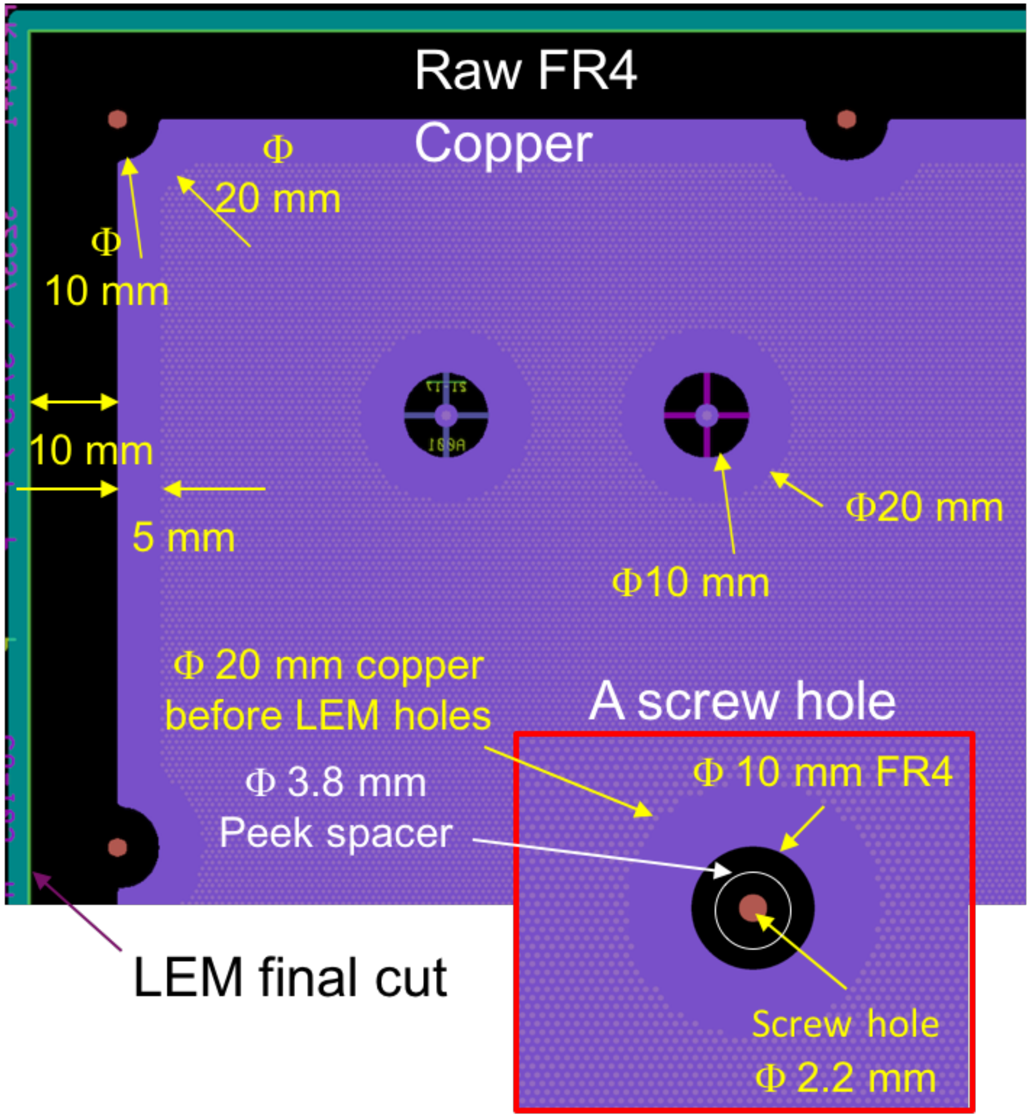

→ increase Grid-LEM distance from 10 to 12 mm (decrease C) ?
→ add diodes in LEM HV distribution path to lower cross-talks between LEMs ?

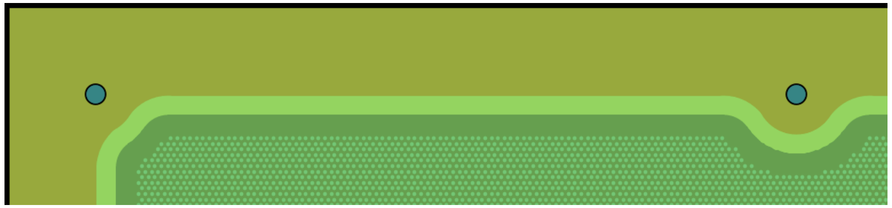
- Drain spark charges through grounding dedicated paths
  → Add a guard ring on the anode, connected to a seperate ground from FEE
  → Add grounded guard ring on the outer frame of the CRP mechanical structure
  → Use resistive path on grid spacers to collect positive ions stuck on Lar surface ?

- Other CRP design modifications (to discuss at tomorrow's session)

# Towards ProtoDUNE-DP phase II
# LEM design

## CFR-35 – NP02



**from modified CFR-35 + pyralux design**

**« secured design » (dvpt time / production)**

- FR4 border decrease : 10 ↘ ~2 mm
- Copper border : 5 ↘ ~2 mm
- Pyralux covering of copper borders
- Φ0,5 ↑ Φ0,6 mm LEM holes on borders ?
- Segmentation ?
- + LEM-Grid HV distribution modification
- + adding a guard ring on anode PCB

**Longer time scale developments (>2022)**

- Resistive LEM (DLC or else)
- Soldermask rings on RIMs
- New ideas for charge readout in DLAr

# Backup slides for discussion

# LEM performances

- ✓ Observation of spark rate dependence on collection electric field
→ secondary sparks in induction gap ? How to mitigate this effect ?
→ need of Electric field simulations for further optimization

- ✓ Positive ions feedback and accumulation on Lar surface ?

- ✓ LEM ageing but no hint of resistive current between LEM sides ?

- ✓ LEM – Grid capacitive coupling depending on LAr stability

  - The quenching resistor does not affect LEM & grid the same way

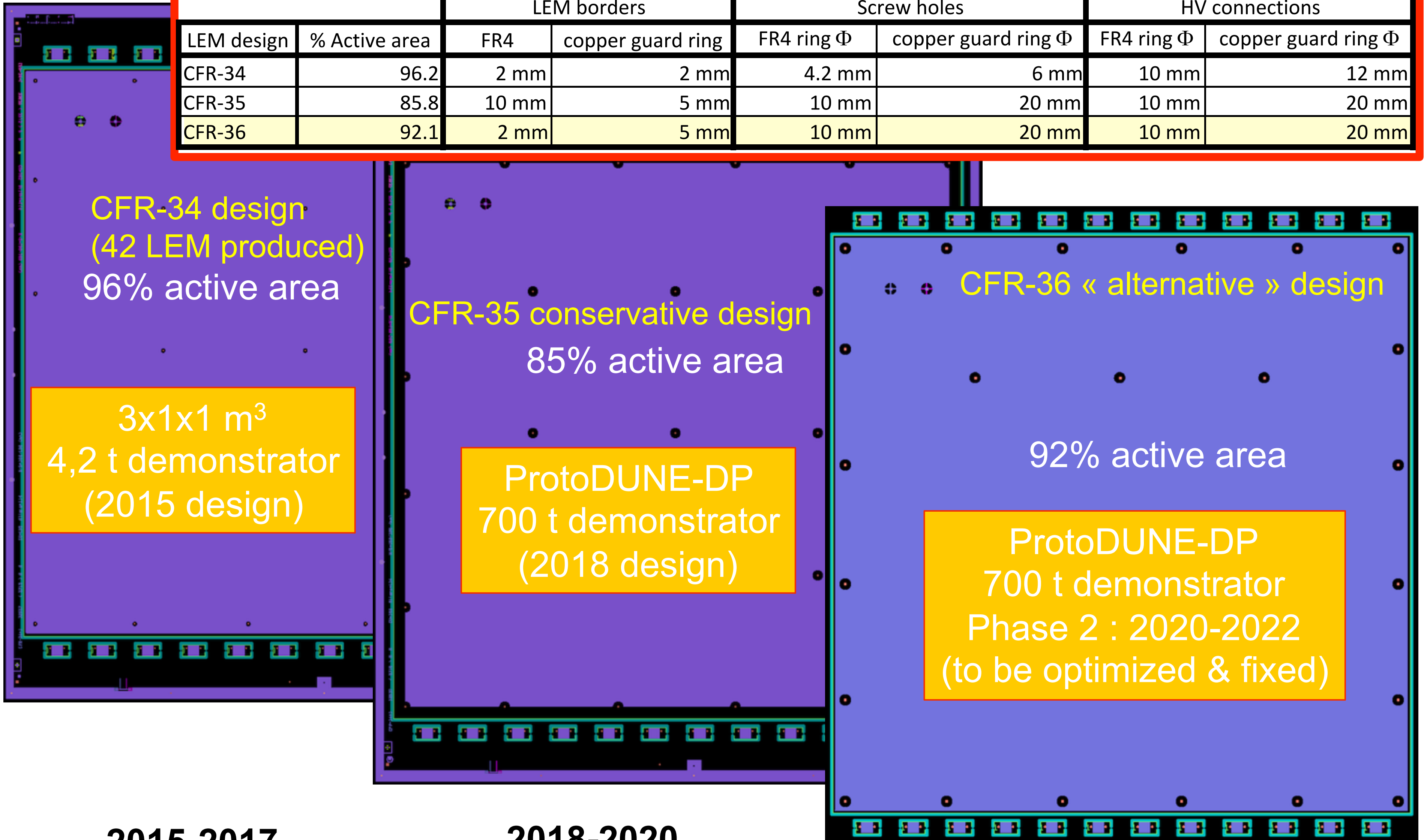
  - Introduction of a coupling capacitance between LEM & Grid ?

- ✓ Explanations for 2 times lower gain derivation from cosmic tracks deposition compared to extrapolation of 3L ETHZ DLAr gain ?

# History of LEM designs

| | | LEM borders | | Screw holes | | HV connections | |
|---|---|---|---|---|---|---|---|
| LEM design | % Active area | FR4 | copper guard ring | FR4 ring Φ | copper guard ring Φ | FR4 ring Φ | copper guard ring Φ |
| CFR-34 | 96.2 | 2 mm | 2 mm | 4.2 mm | 6 mm | 10 mm | 12 mm |
| CFR-35 | 85.8 | 10 mm | 5 mm | 10 mm | 20 mm | 10 mm | 20 mm |
| CFR-36 | 92.1 | 2 mm | 5 mm | 10 mm | 20 mm | 10 mm | 20 mm |

?

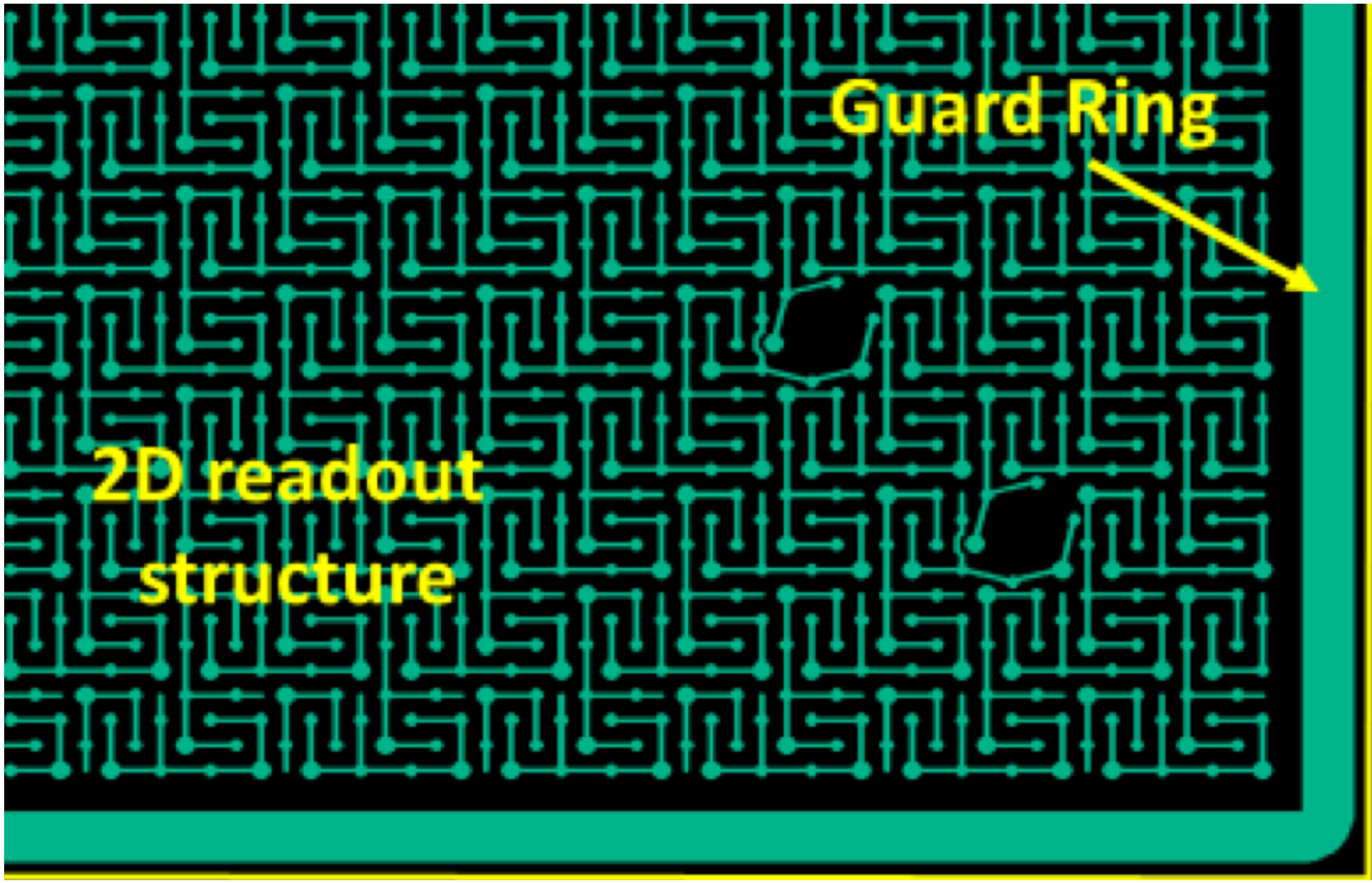



**2015-2017** **2018-2020**

**2020-2022 → DUNE FAR ?**

# Anode guard ring

- New design with a guard ring on both faces of the PCB **(3 mm < LEM dead zone)**
- to mitigate risks associated with sparks causing damages to the FE electronics
- 2 prototypes will be ordered to PCB industrial partners ELTOS (it.) and ELVIA (Fr.).

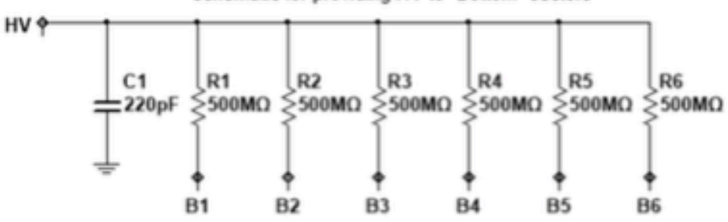


# INFN/COMPAS-RICH THGEM
# HV distribution

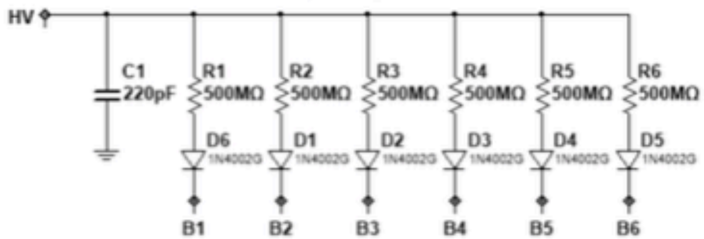
## HV distribution to the THGEM, the issue of discharge propagation between sectors, a possible wayout

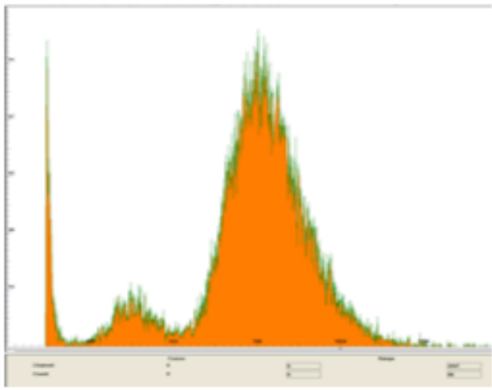
Discharge effect propagation from one sector to others (also non adjacent ones!) lowering voltage and reducing the neighboring sectors efficiency
HV distribution suspected.

schematic for providing HV to "Bottom" sectors

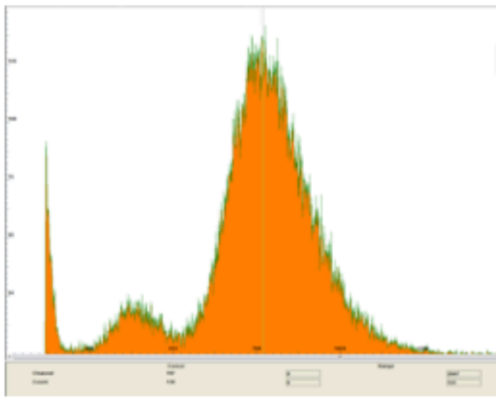



Schematic for providing HV to Bottom sectors with diodes



Collect spectra on one sector before and after a trip occurs in another sector ( induced )
Comparison of the two spectra just before and after a trip in next to it sector.



Analogous scheme also for the top
Diode: VS-20ETS High Voltage, Input Rectifier Diode

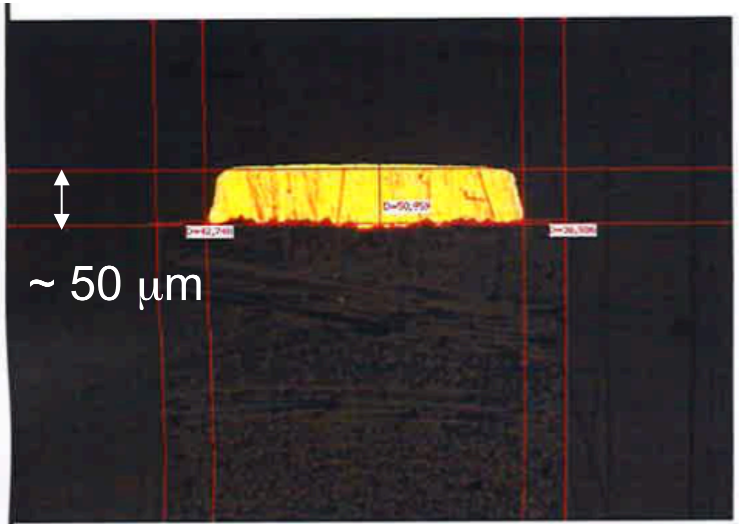
*Instrumentation Days on Gaseous Detectors* - 12-13 octobre 2016 - Campus Cézeaux, Université Blaise Pascal, Clermont-Fd - Stefano Levorato 38

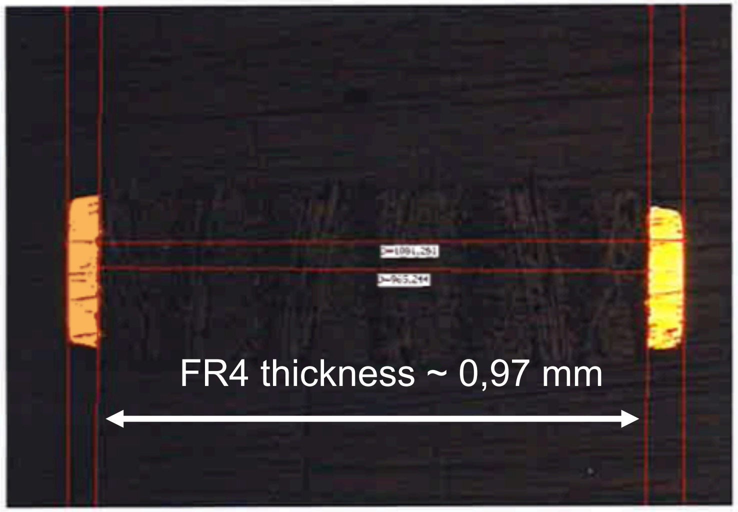
# CFR-34 & CFR-35 (ELTOS) Common specifications

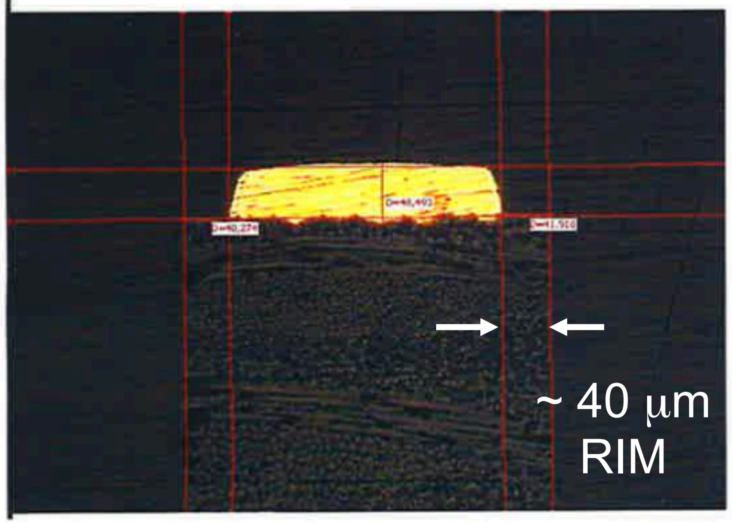
| | |
|---|---|
| Laminate specifications | |
| Laminate | FR4 epoxy PANASONIC R-1566W |
| Dimensions | 530 mm x 540 mm |
| Bare FR4 epoxy thickness | 1 mm (-0.05 /+0 mm) Meas. 0,98 mm |
| Copper thickness | 105 μm |
| Mean thickness | 1,20 (-0.06/+0) mm |
| Thickness uniformity | +/- 0.04 mm |
| final LEM specifications | |
| Dimensions | 499.5 mm x 499.5 mm +0/-0.3 mm |
| Ni/Au | 5 μm Ni + 0.1 μm Au |
| Final thickness | 1.10 (-0.05/+0.02) mm Meas. : 1,11-1,12 mm |
| LEM holes | ≈ 400 000 non-plated Φ=0.5 mm -0/+0.01 mm Meas. +0,003 mm |
| RIM (with Ni/Au) | 40 μm +/- 4 μm Meas. : 37 - 42 μm |

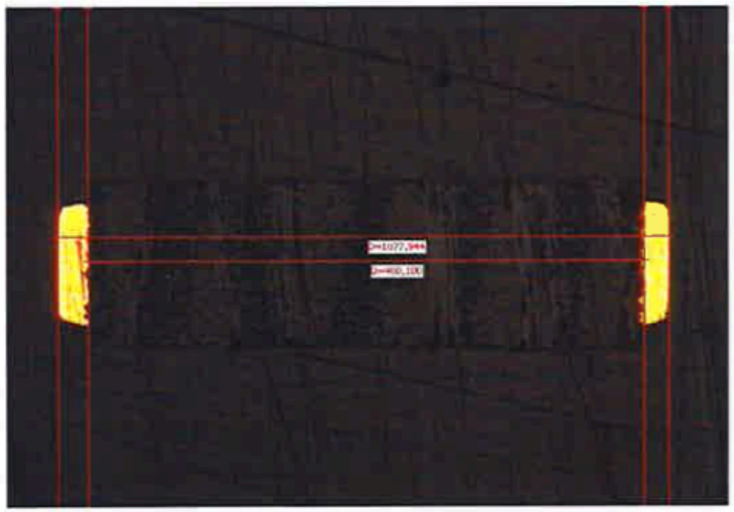
# CFR-35 metallographic sections
# Standard RIM global etching

metallographic sections : 1.07 mm total thickness (~0,97 FR4 + 0,1 copper+Ni/Au)



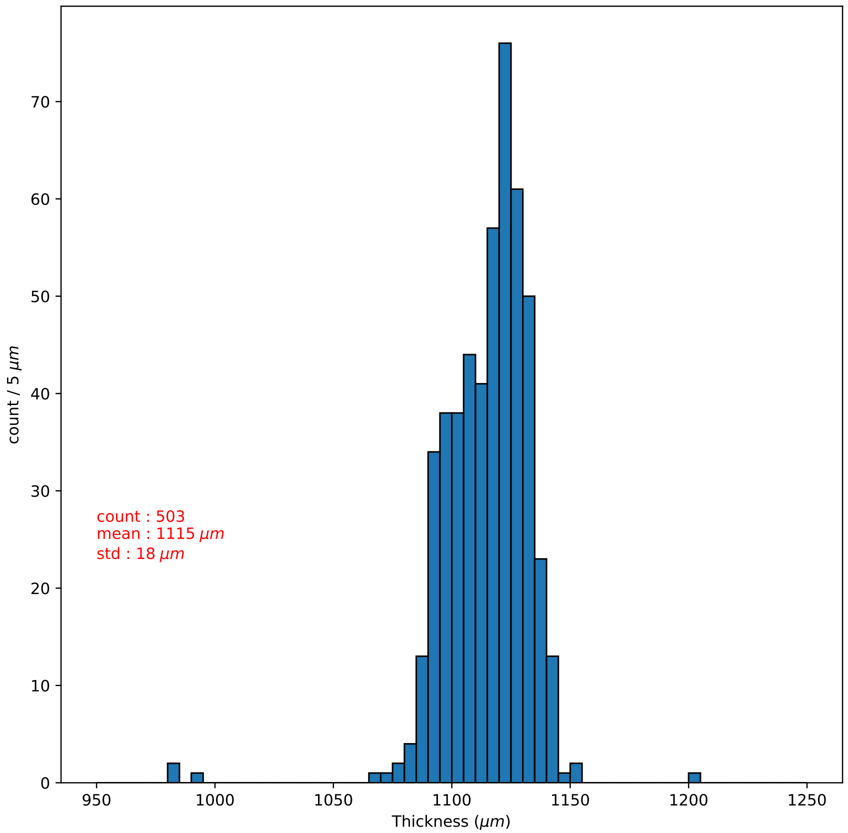



# LEM thickness measurement @ Saclay

Ph. Cotte PhD defense, sept 2019

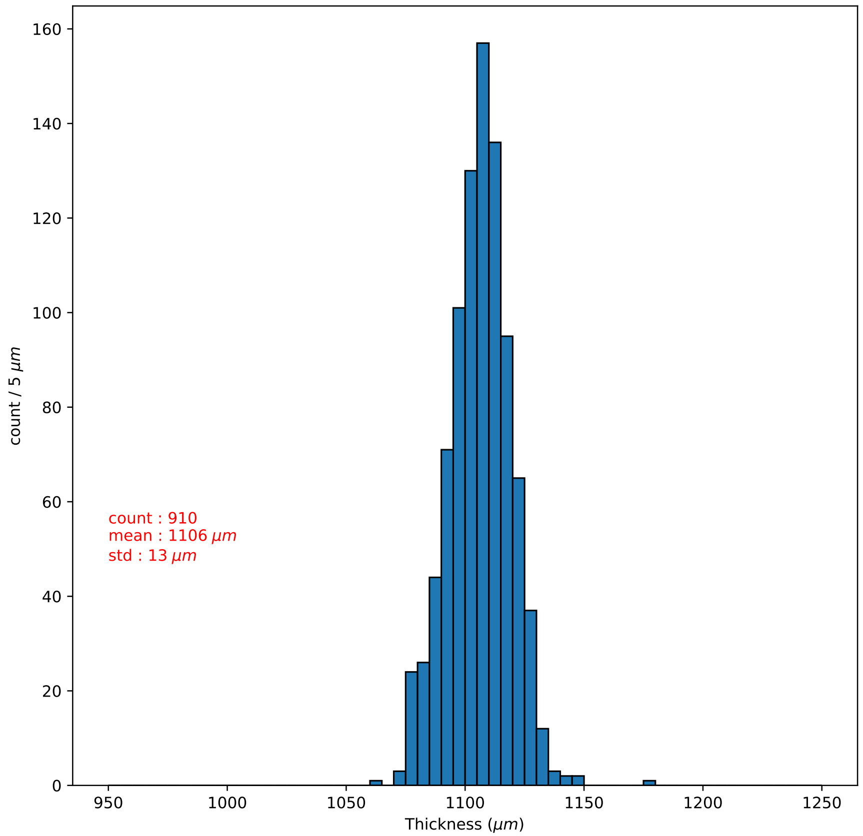
## CRP#1 LEMs

Mean LEM thickness : 1.115 mm




## CRP#2 LEMs

Mean LEM thickness : 1.106 mm

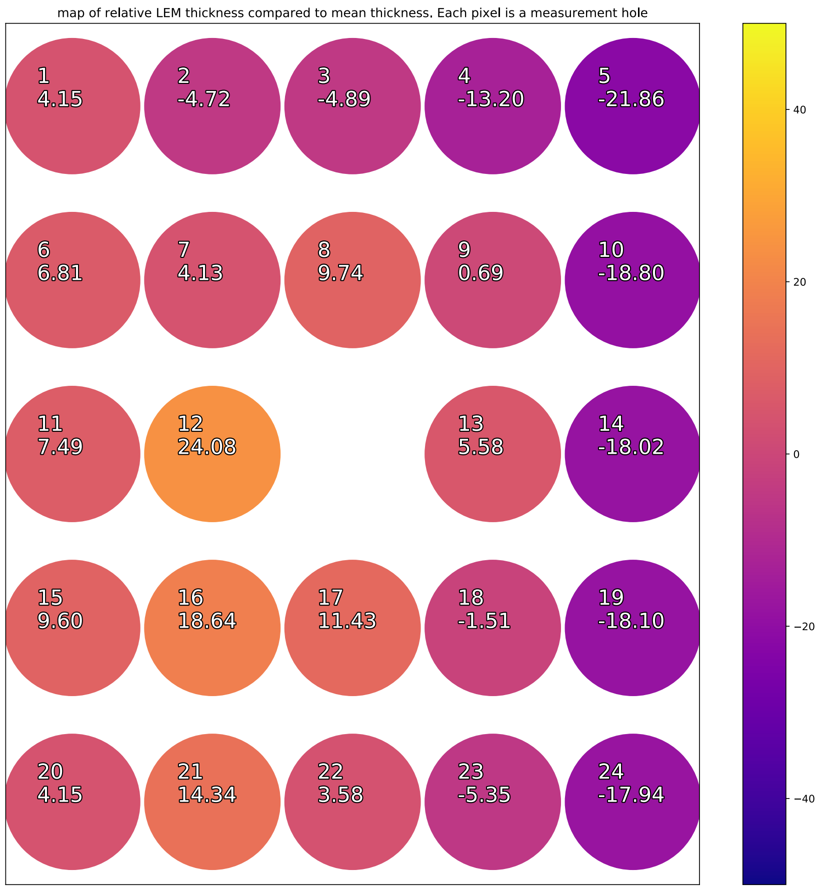



Specification : 1,10 mm -0,05/+0,02 mm

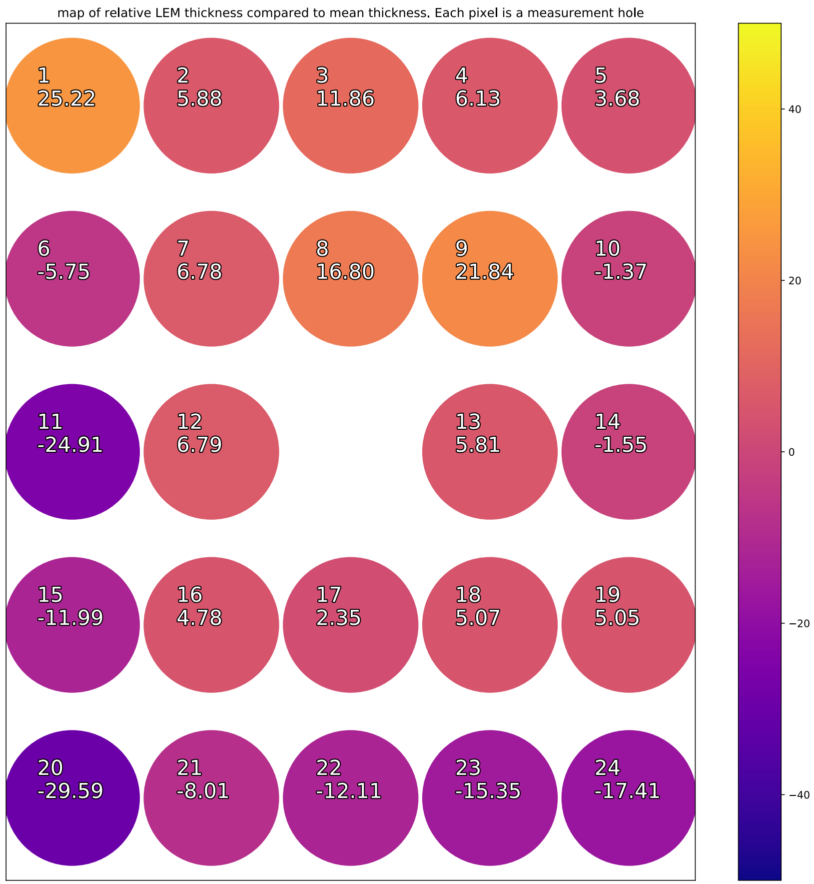
# LEM thickness measurements @ Saclay : uniformity over LEM surface

Ph. Cotte PhD defense, sept 2019

LEM CRP#1/A081 Mean thickness : 1,112 mm
+ 24 μm / - 22 μm




LEM CRP#2/A120 Mean thickness : 1,111 mm
+ 25 μm / - 30 μm

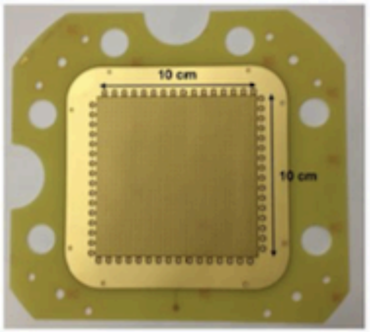


# 10x10 LEM sparking

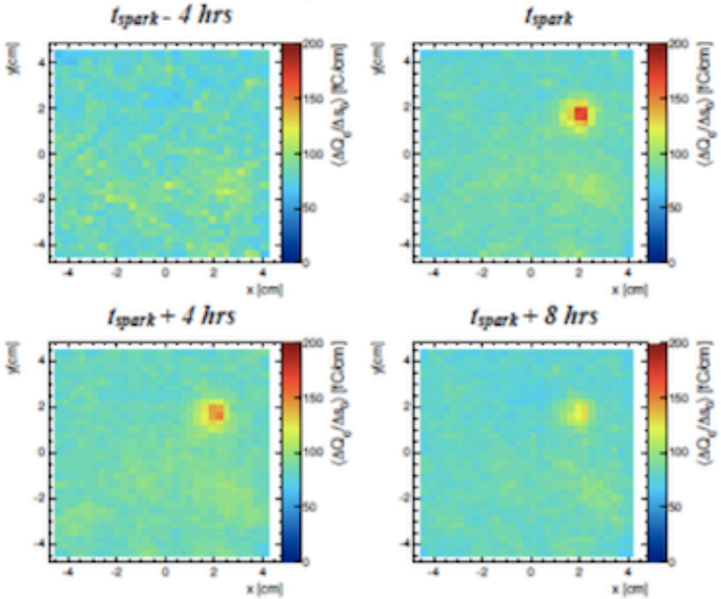
## LEM charging up, sparks and long-term performance

**C. Cantini et al., arXiv:1312.6487**

***ETHZ 10×10 prototype***

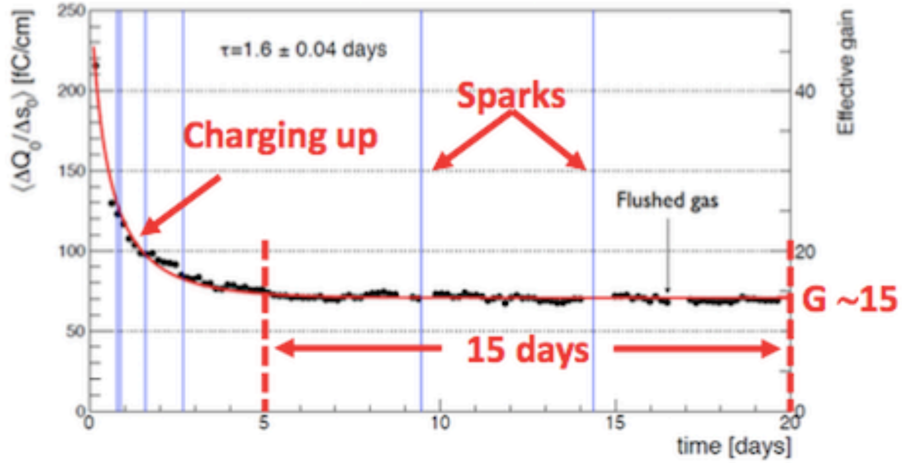



***LEM spark history***




***LEM charging up destroyed locally (~cm$^2$) after a spark***

***LEM dielectric charging up due to E-field lines crossing walls around holes***

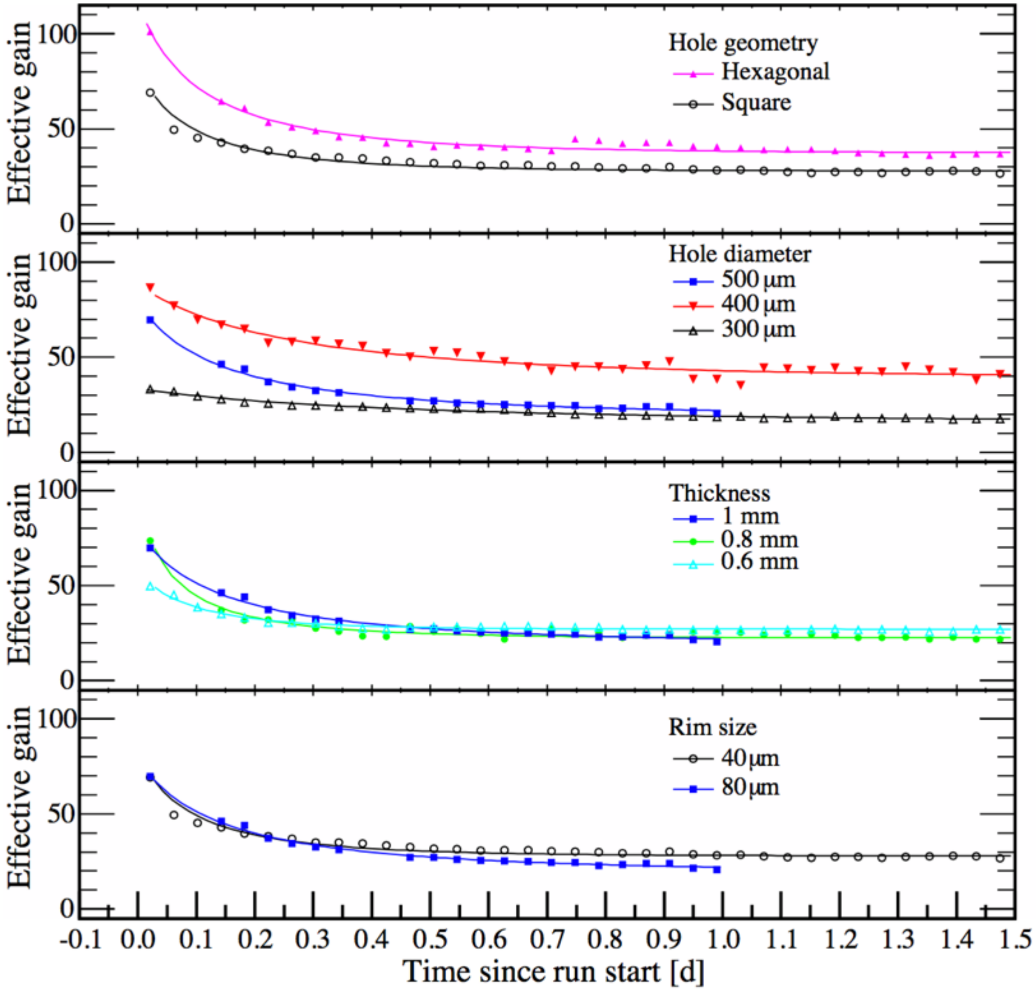


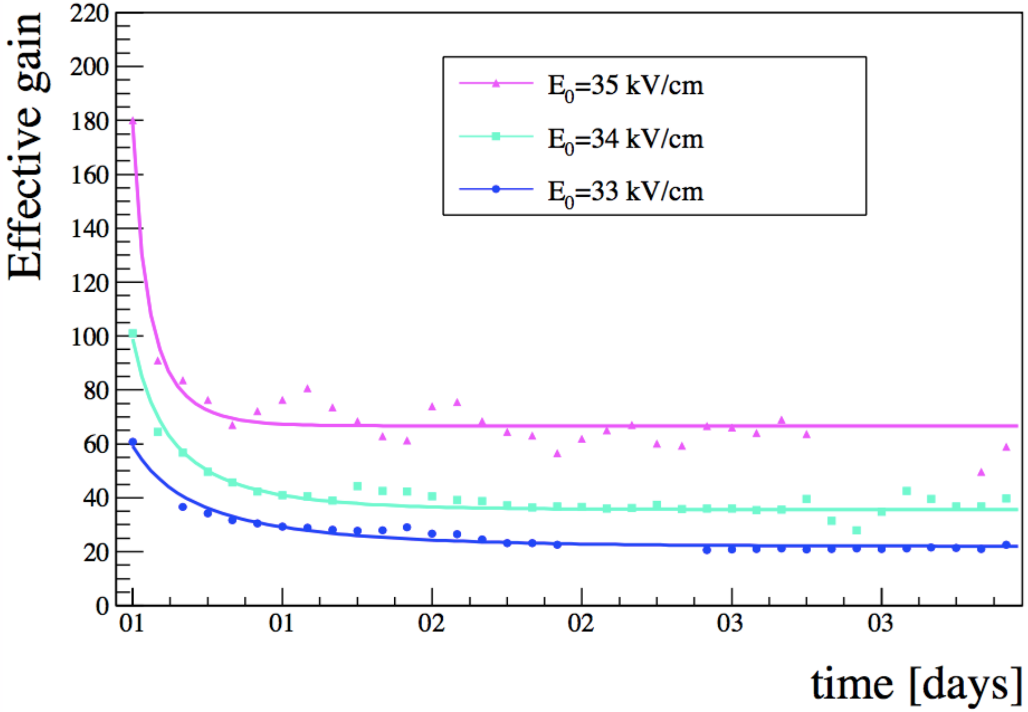

- ***2 sparks in 15 days after charging up***
- ***Extrapolation to 3m×3m :***
  ***(5.0±3.5) sparks/h @ G~15***

06/04/2020 Workshop on the LEM/Thick GEM cryogenic utilization in pure Argon over large detection surfaces 7

# LEM charging-up

C. Cantini et. Al, JINST **10** (2015)



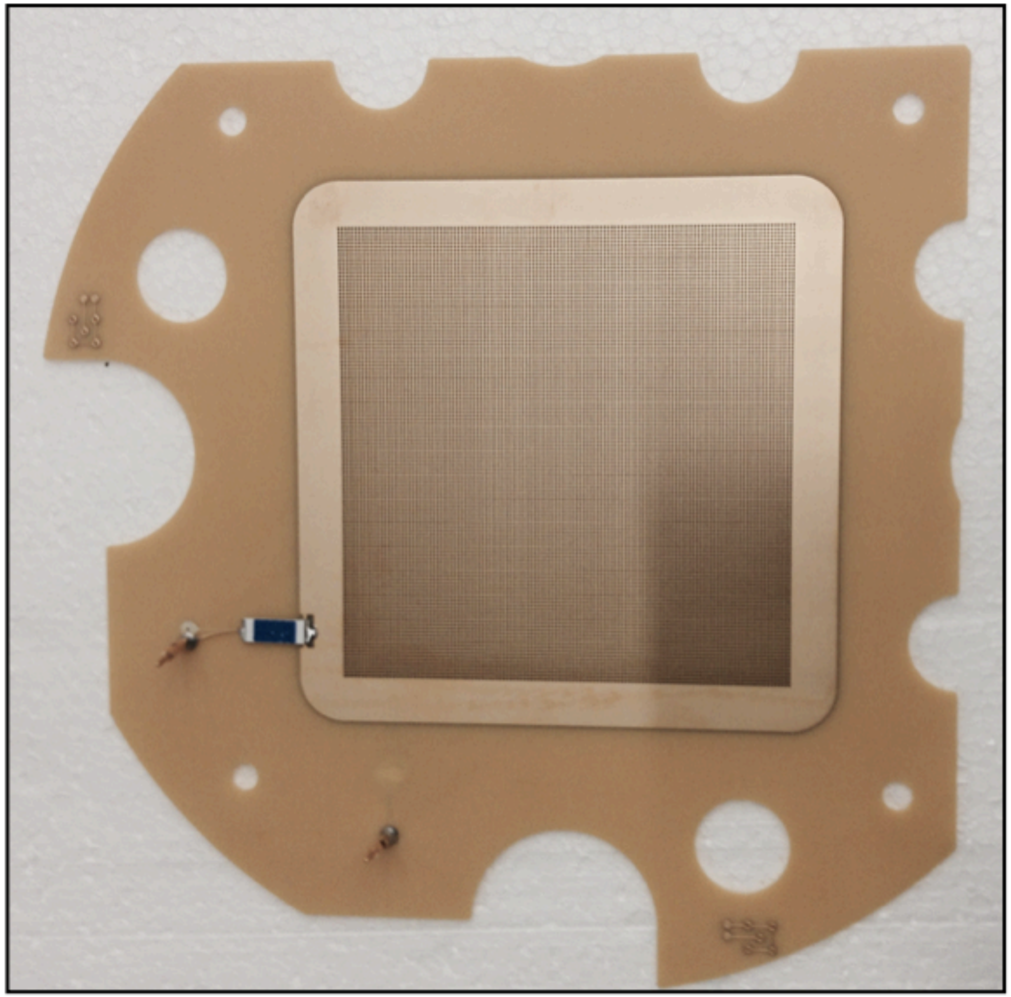



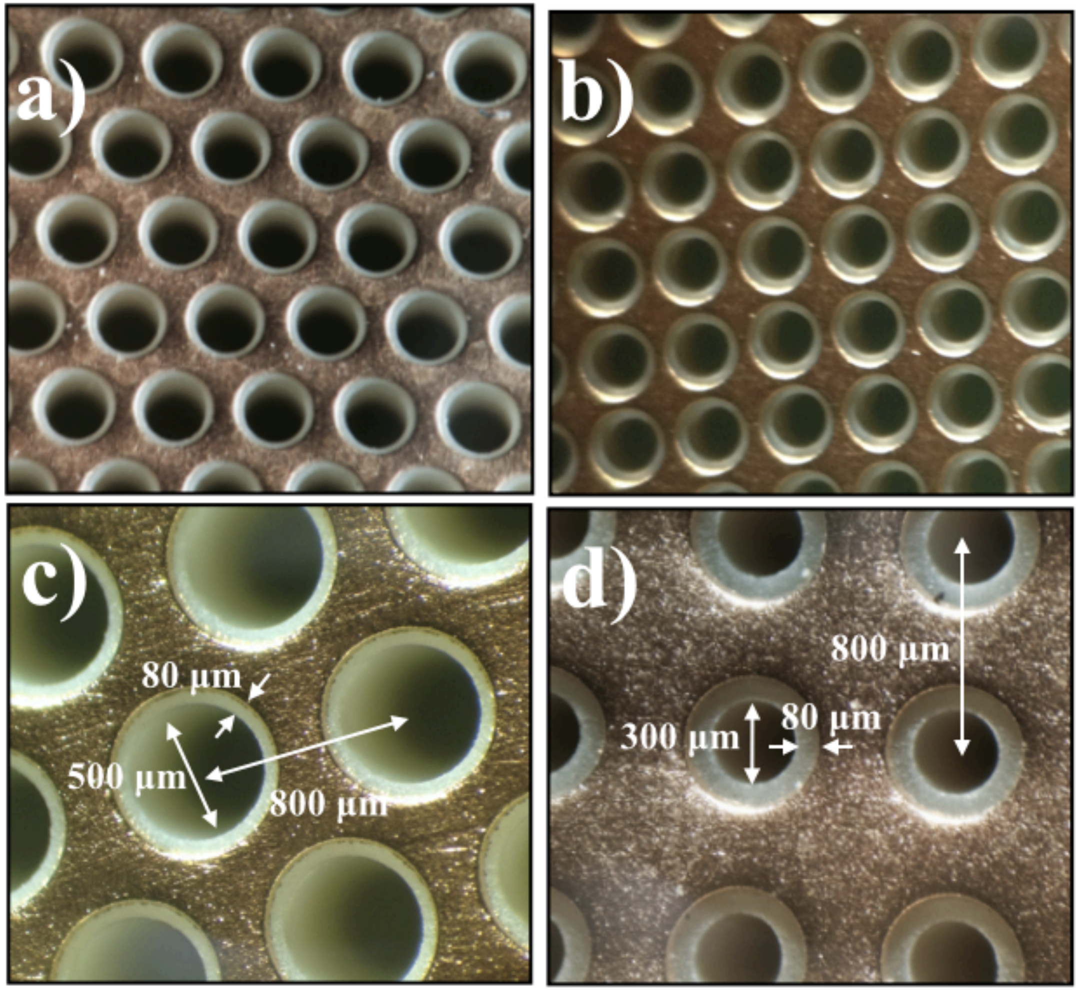

Charging-up effect on gain drop value & time behaviour depends on amount of FR4 material : RIM size, hole diameter, LEM thickness, density of holes

measured ~3.3 in 2-3 h for ProtoDUNE-DP LEMs at Saclay with $^{251}$Am $\alpha$ source

# LEM holes modifications ?

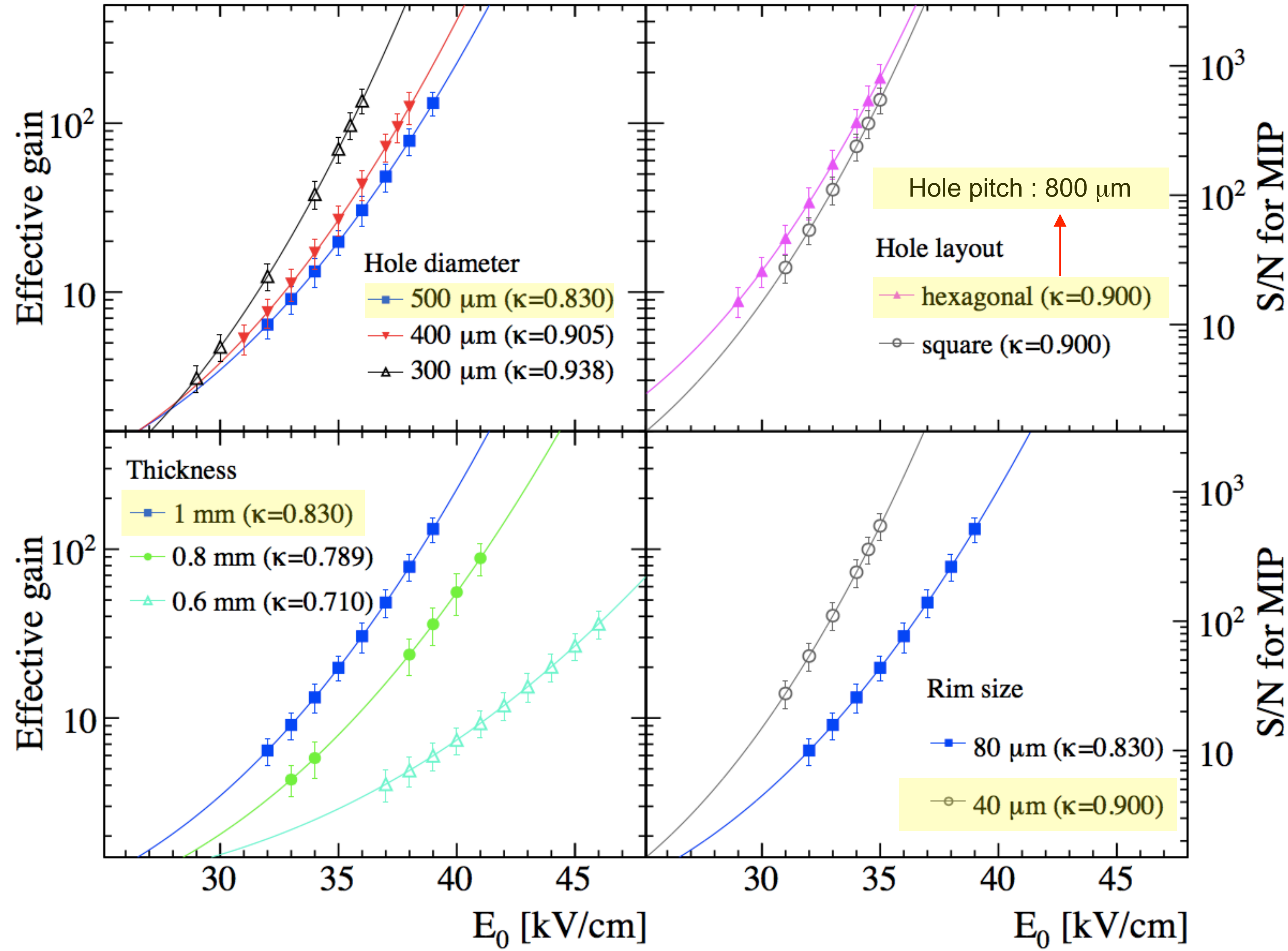
10x10 cm$^2$ with large FR4 border






C. Cantini et. Al, « Performance study of the effective gain of the double phase liquid Argon LEM Time Projection Chamber, JINST **10** (2015)

# LEM key parameters

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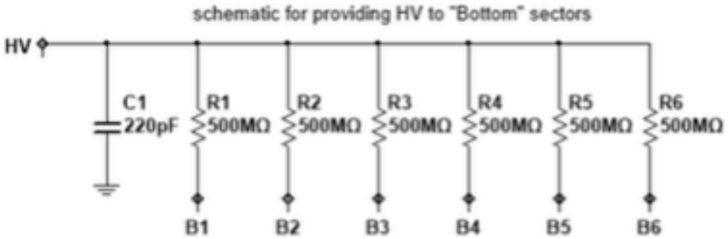


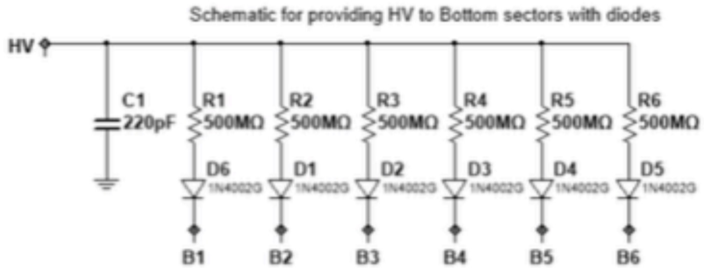


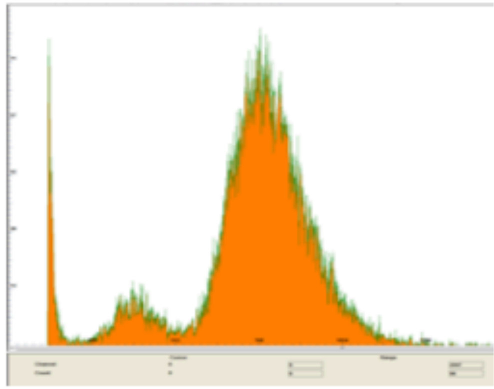

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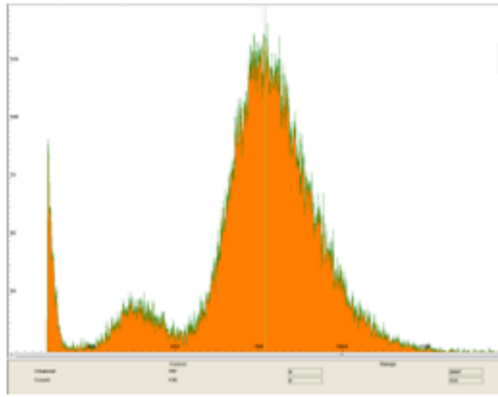
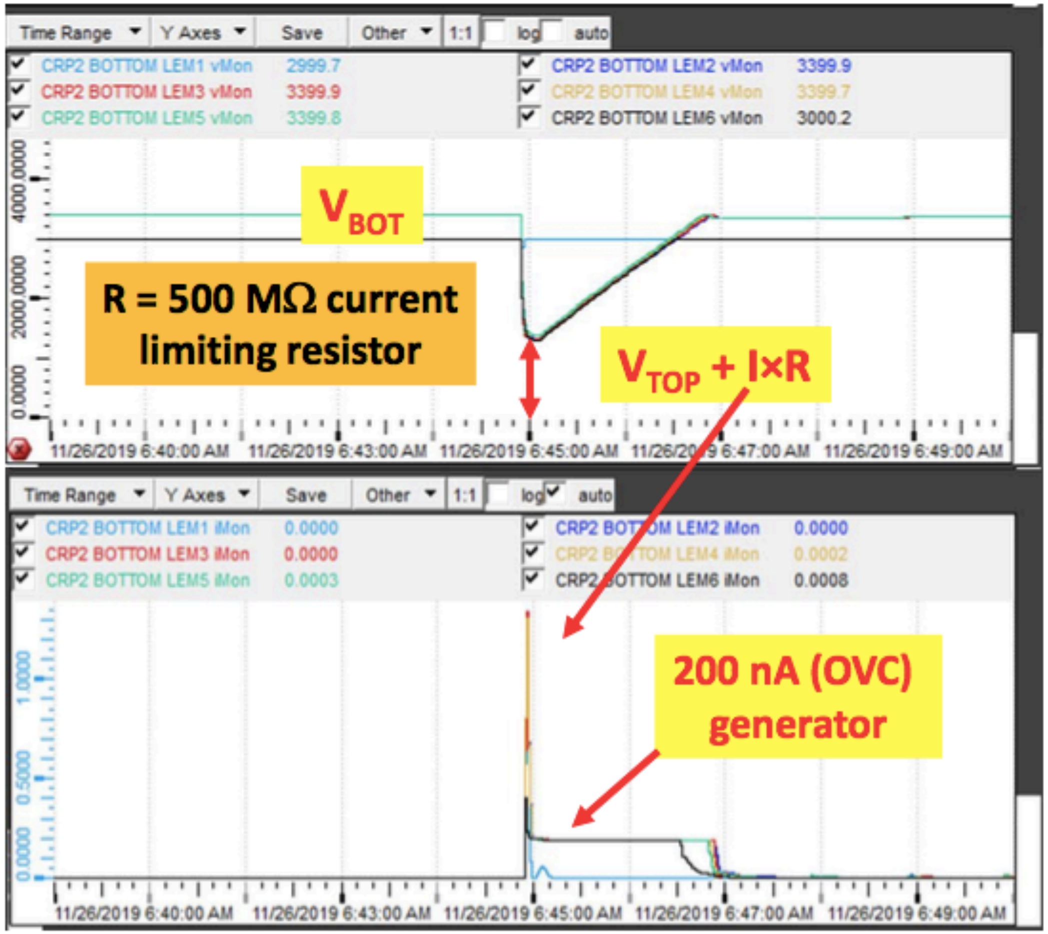
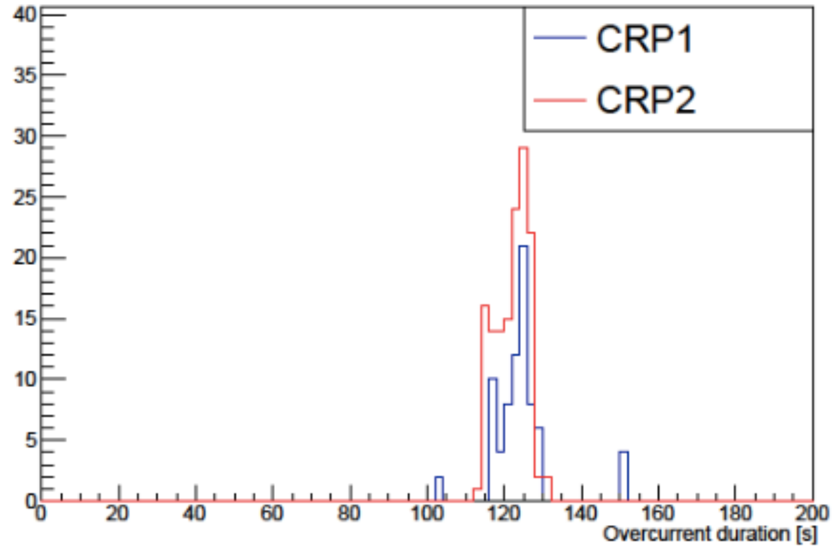


Analogous scheme also
for the top
Diode: VS-20ETS High Voltage, Input Rectifier Diode

# ProtoDUNE-DP
# LEM HV slow-control

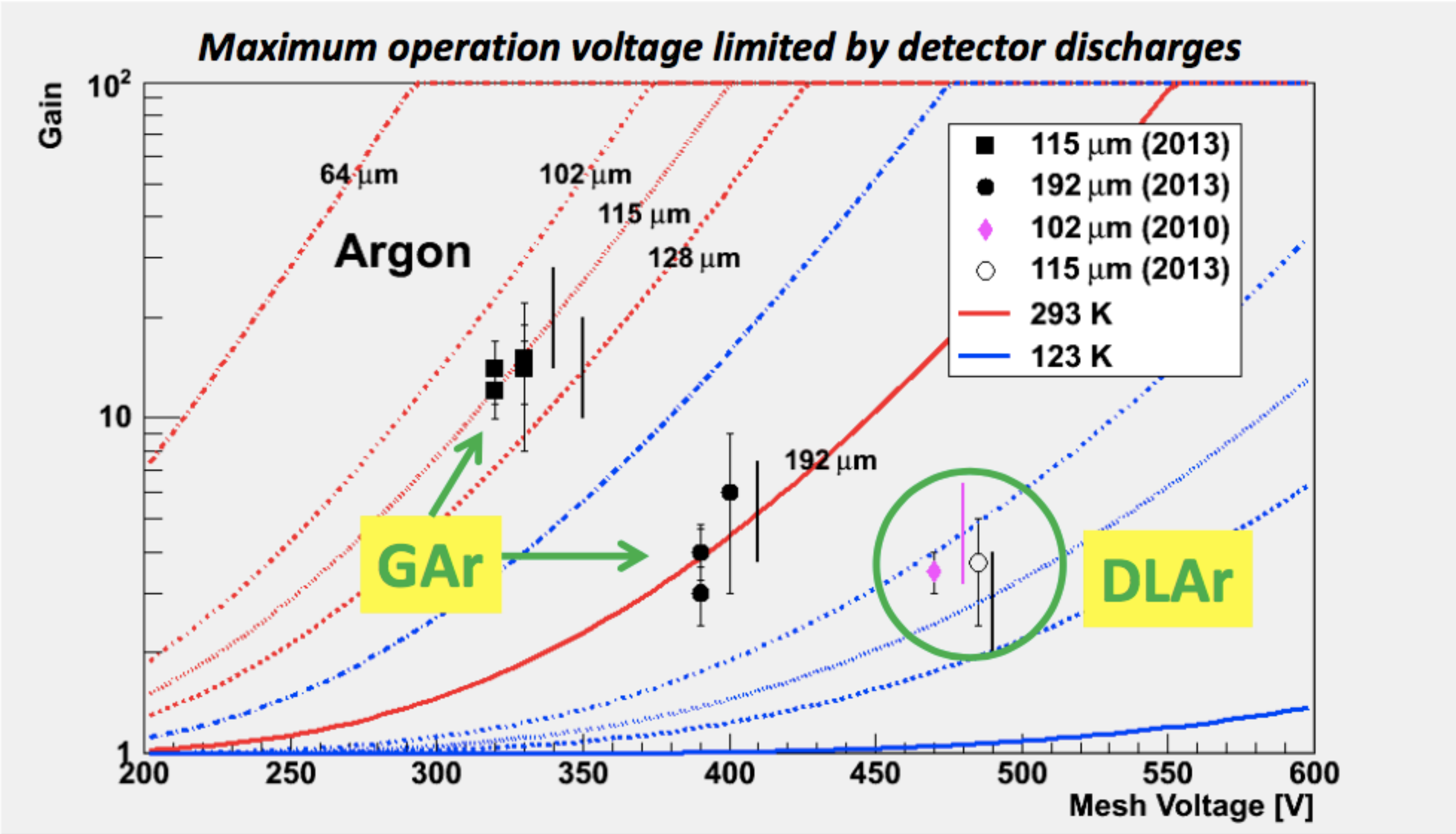



***Dead time due to a LEM spark is set to 2 minutes. Not an issue for rates at the level of a several sparks per hour and per CRP.***

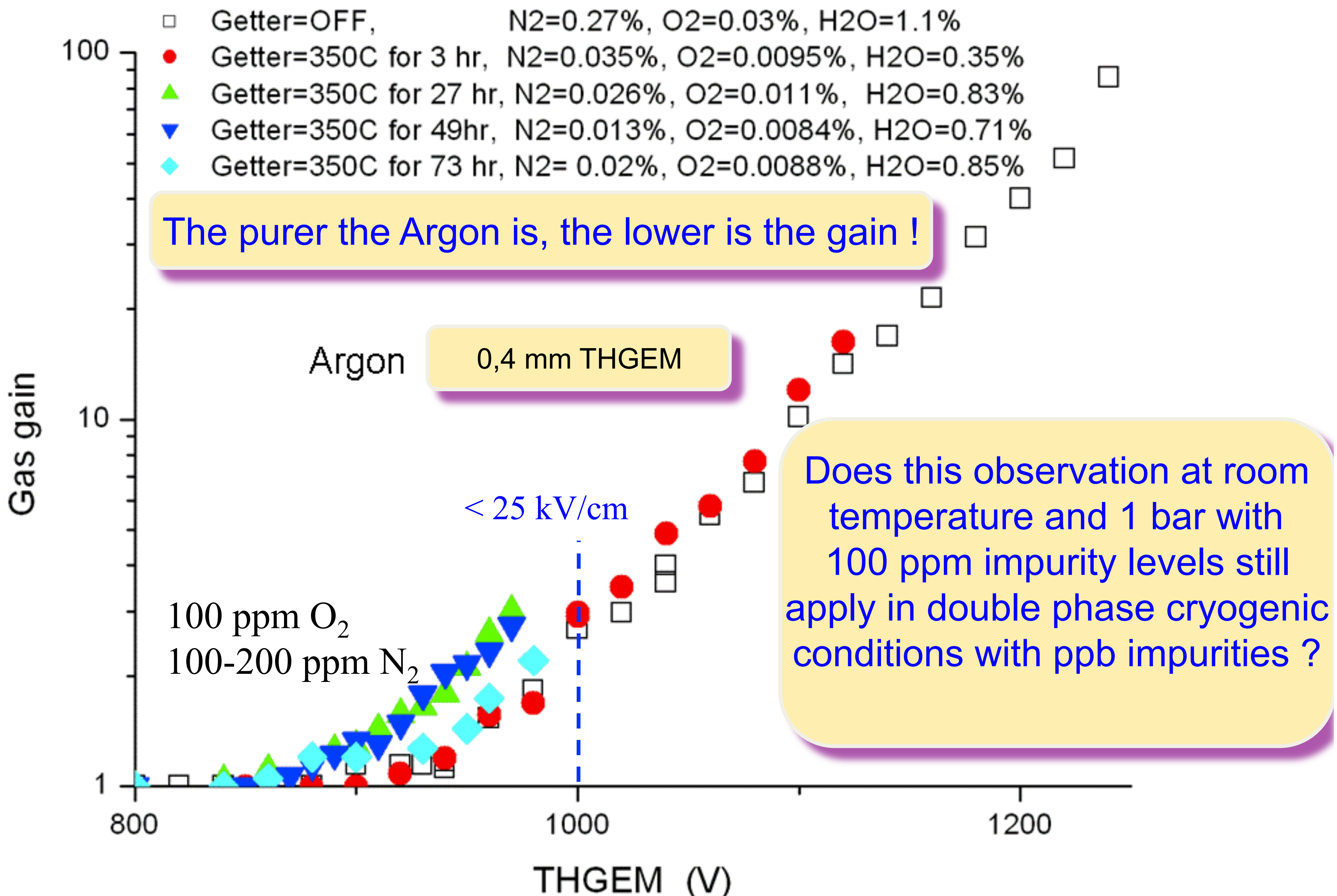
# Micromegas for Dual phase Lar-TPC ?

$$G \sim e^{\alpha(p,T,V)d} \quad \text{with} \quad \alpha = (Ap/T)e^{-Bpd/VT}$$




E. Mazzucato, WA105 kick-off meeting, CERN, october 15-17, 2014

# Gain limits in pure Argon : a possible explanation ?




Ref: J. Miyamoto, A. Breskin and V. Peskov, JINST 2010, doi:10.1088/1748-0221/5/05/P05008

# Effective gain